

(21) Application No 9914530.2

(22) Date of Filing 23.06.1999

(71) Applicant(s)
Motorola Limited
(Incorporated in the United Kingdom)
Jays Close, Viabes Ind Est, BASINGSTOKE,
Hampshire, RG22 4PD, United Kingdom

(72) Inventor(s)
Nicholas William Anderson
Rorie Julian Turnbull O'Neill

(74) Agent and/or Address for Service
Peter D Hudson
Motorola Limited, European Intellectual Property
Department, Midpoint, Alencon Link, BASINGSTOKE,
Hampshire, RG21 7PL, United Kingdom

(51) INT CL⁷
H04B 7/005

(52) UK CL (Edition R)
H4L LDH L1H10

(56) Documents Cited
EP 0853393 A1 EP 0847146 A2 EP 0715423 A1
EP 0709973 A1 WO 98/58461 A1 WO 97/34434 A1
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(58) Field of Search
UK CL (Edition Q) **H4L LDH**
INT CL⁶ **H04B 7/005 , H04Q 7/32**
ONLINE - EPODOC, WPI

(54) Abstract Title
Power control in a radio communication system

(57) Apparatus for controlling transmitter power in a radio communication system, particularly a CDMA system, has an inner power control loop for producing a power control metric estimate PCM_{Est} , and an outer power control loop for producing an outer loop threshold signal OLT dependent on received quality of service (QoS). The PCM and OLT signals are compared with one another (Fig.1) to control transmit power. The outer control loop has means to produce a channel error rate signal ChER to track channel variations. The ChER signal is produced as a re-encoded channel error metric ReEnc_ChER by decoding and then re-encoding the output of a receiver/demodulator (20, Fig.2) and comparing the reencoded signal with the output of the receiver/demodulator. The outer control loop itself is a dual loop with a first loop 36 which monitors QoS information in the form of frame cyclic redundancy (CRC) pass/fail events $CRC_{p/f}$ and in response sets a target channel error rate $ChER_{Target}$ for a second loop 40 of the dual outer loop. The second outer loop 40 attempts to maintain the target channel error rate by comparing this target with a filtered version of ReEnc_ChER, the output of this comparison driving a small gain step incrementer/decrementer 42. In response to the CRC pass/fail events, the first outer loop 36 also produces an output which drives a big gain step incrementer/decrementer 38. The outputs of the incrementers/decrementers 38 and 42 are combined to adjust the OLT for the inner control loop, the first outer loop 36 adjusting OLT in large steps, and the second outer loop 40 adjusting OLT in smaller steps. The power control is capable of compensating for variations in the channel type and user speed, and the dual outer loop arrangement allows desired QoS to be maintained for low-frame-error- rate (FER)/high-data-rate services.

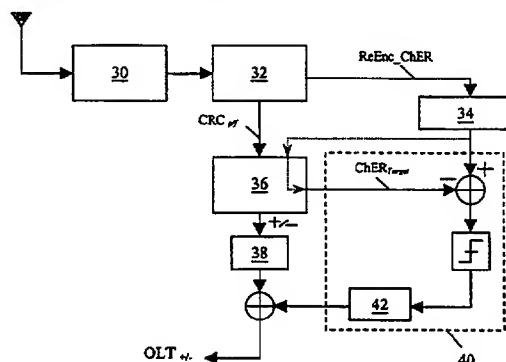


FIG. 3

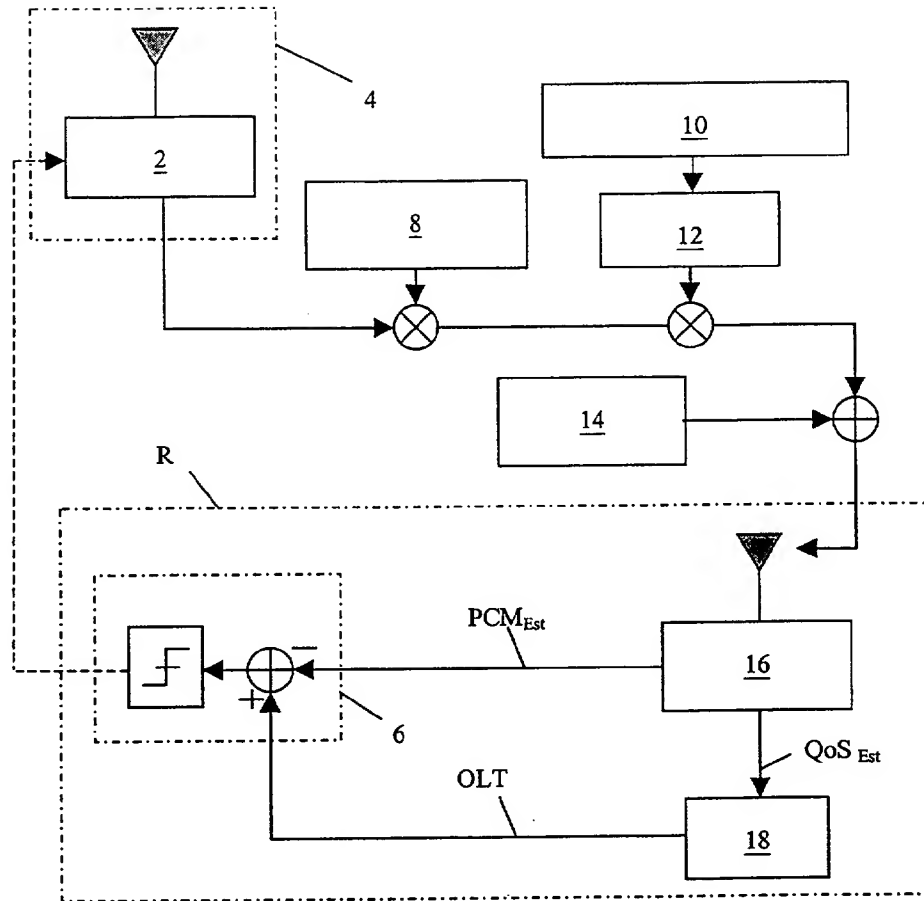


FIG. 1
PRIOR ART

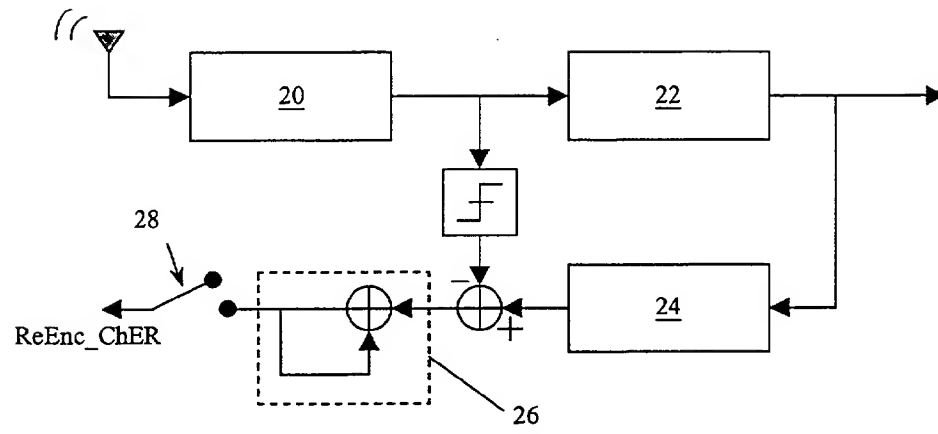


FIG. 2

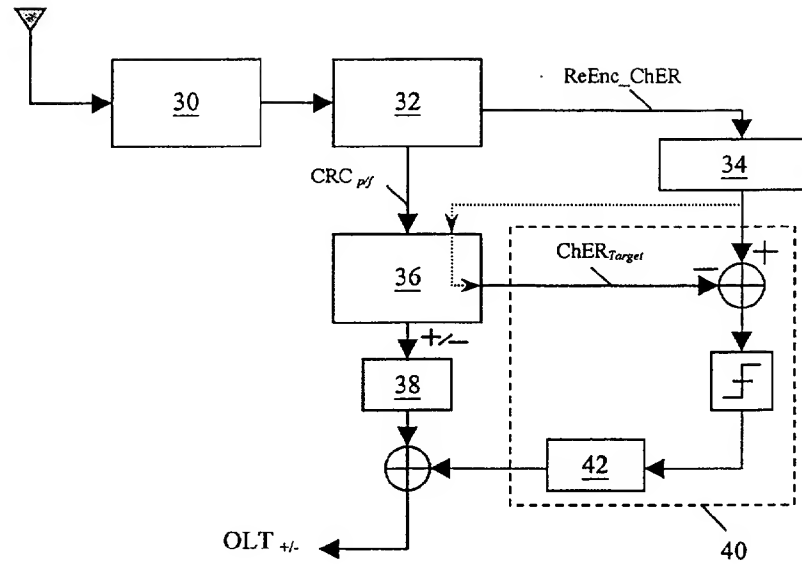


FIG. 3

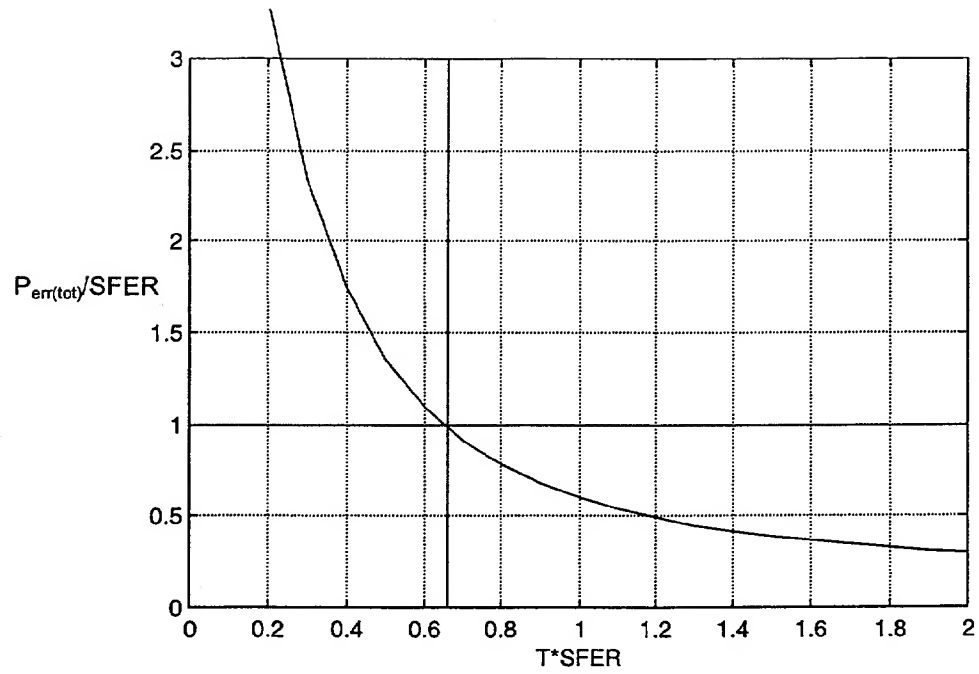


FIG. 4

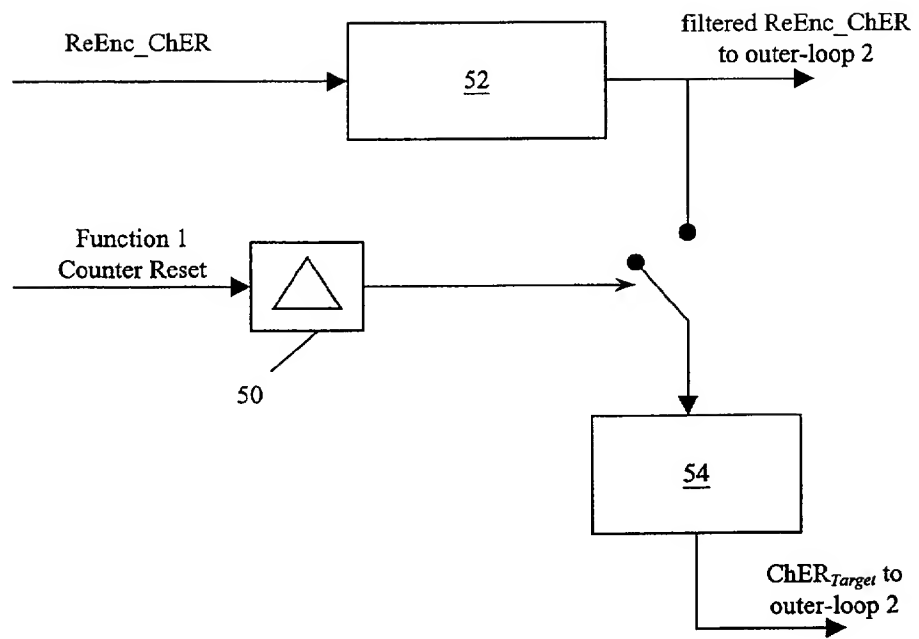


FIG. 5

APPARATUS AND METHOD FOR POWER CONTROL IN A RADIO
COMMUNICATION SYSTEM

5 **Field of Invention**

This invention relates to power control in radio communications systems such as CDMA cellular telephone systems.

10

Background of Invention

'Outer loop' power control is required in a CDMA system to set an appropriate target for the 'inner loop' power control loop which is just high enough to achieve the desired quality of service (QoS). This target point value will vary as a function of channel propagation (e.g., dispersiveness or user speed). Without effective power control, users perceived QoS will be severely degraded or network capacity will degrade (as a result of excess power transmission when exceeding desired QoS).

25 In particular, dynamic outer-loop power control is required in a CDMA system in order to adjust the E_b/N_o (the ratio of energy per bit to noise power spectral density) target point for an inner power control loop in order to track changes in channel propagation in an attempt to maintain constant QoS.

30

Future generations of cellular telephone services such as the proposed Universal Mobile Telephone System (UMTS) will offer a plethora of different services, each with quite different QoS requirements in terms of delay, bit error rate (BER) and frame erasure rate (FER). This represents a challenge to mobile radio equipment manufacturers who must therefore design their products to be fully adaptable to these various requirements.

10

Traditional methods for performing outer-loop power control, such as those based on the 'sawtooth' algorithm employed in existing CDMA networks (e.g., the IS-95 cellular standard), are not appropriate for all service types. This is especially true of low FER or high delay services (e.g., video) - which are to be deployed in next generation networks across the world.

20 **Summary of Invention**

In accordance with a first aspect of the present invention there is provided an apparatus as claimed in claim 1.

25

In accordance with a second aspect of the present invention there is provided a method as claimed in claim 6.

30

Brief Description of Drawings

One embodiment of the invention will now be described, by way of example only, with reference to the

5 accompanying drawings, in which:

FIG. 1 shows in block diagrammatic form a system incorporating inner- and dynamic outer-loop power control as known in the prior art;

10 FIG. 2 shows in block diagrammatic form a scheme for re-encoded channel error rate measurement as employed in the preferred embodiment of the present invention;

15 FIG. 3 shows in block diagrammatic form a system in accordance with a preferred embodiment of the present invention incorporating a dual outer loop power control scheme (DOLAP);

FIG. 4 shows a graph used in deriving an appropriate value for a counter parameter of the system of FIG. 3; and

20 FIG. 5 shows a block schematic diagram of a target channel error rate ($\text{ChER}_{\text{Target}}$) update scheme employed in the system of FIG. 3.

25 **Description of Preferred Embodiment**

Two-loop (inner-loop and outer-loop) power control is known in CDMA cellular telephone systems. Dynamic outer-loop power control is required in a CDMA system
30 in order to adjust the E_b/N_0 target point for the inner power control loop in order to track changes in channel propagation (e.g., dispersiveness/user speed). Without

effective dynamic outer-loop power control, users perceived QoS will be severely degraded or network capacity will degrade (as a result of excess power transmission leading to excessive QoS).

5

A diagram depicting inner- and dynamic outer-loop power control is shown in FIG. 1. In this arrangement, the transmit power 2 of a transmitter 4 is controlled via an inner loop 6 contained within a receiver unit R. The
10 inner loop 6 includes inputs from the transmitted power, a shadow (slow) fading profile 8, a fast-fading profile 12, and noise interference 14. The fast-fading profile 12 is itself dependent on the channel variation (e.g., speed/dispersion) 10. For the inner loop 6,
15 receiver circuitry 16 produces from the signal received at the receiver R a power control metric estimate (PCM_{Est}) - a function of received E_b/N_o - which is used to modulate the transmit power 2 of the transmitter 4. Additionally, an outer loop 18 is also used to control
20 the transmit power 2 of the transmitter 4. In the outer loop 18 a quality of service estimate (QoS_{Est}) is derived from the signal received at the receiver R and is used to produce an outer loop threshold (OLT) signal. The PCM estimate signal PCM_{Est} from the inner
25 loop 6 and the OLT signal from the outer loop 18 are compared and the result is used to control the transmit power 2 of the transmitter 4.

Future generations of cellular telephone services such
30 as the proposed Universal Mobile Telephone System (UMTS) will offer a plethora of different services, each with quite different QoS requirements in terms of

delay, bit error rate (BER) and frame erasure rate (FER). This represents a challenge to mobile radio equipment manufacturers who must therefore design their products to be fully adaptable to these various requirements.

Traditional methods for performing outer-loop power control, e.g., the outer power control loop scheme (based on the 'sawtooth' algorithm) commonly deployed in IS-95 CDMA networks, are not appropriate for all service types. This is especially true of low FER or high delay services (e.g., video) which are to be deployed in next generation networks across the world.

The 'sawtooth' algorithm can be described as follows:- QoS information in the form of frame cyclic redundancy check (CRC) pass/fail is available from the receiver. The frame quality indicator flag q_k is set to +1 in the event that the k^{th} received frame was bad, and is set to -1 in the event that the k^{th} received frame was good. A function $f(q_k)$ returns the outer loop step increment based on the QoS input information q_k where:-

$$f(q_k) = -\Delta \text{ for } q_k = -1 \text{ and } f(q_k) = +K\Delta \text{ for } q_k = +1 \quad (1)$$

That is, for every good frame received the OLT is decreased by an amount Δ , whereas for every bad frame received the OLT is increased by an amount $K\Delta$. Using the given notation the algorithm can be expressed in a more mathematical form as:-

$$OLT(k+1) = OLT(k) + \frac{1}{2} \{ (q_k + 1)K\Delta + (q_k - 1)\Delta \} \quad (2)$$

A value of K can be derived as a function of the desired FER:-

$$K = \frac{1 - 2FER_{target} + 1}{1 + 2FER_{target} - 1} = \frac{1}{FER_{target}} - 1 \quad (3)$$

Therefore, suppose for example an FER of 1% is desired,
5 then for every good frame received the algorithm decreases the OLT by an amount Δ , whilst for every bad frame received the OLT is increased by 99Δ . This results in the desired FER being attained.

- 10 An unwanted transmission power overhead, that is a function of $K\Delta$, is required by the sawtooth algorithm in order for it to attain the desired FER_{target} . Thus, it will be understood that the excess power transmitted due to the dynamic outer-loop increases with $K=1/FER_{target}$
15 and this is where one of the problems with low FER UMTS services becomes apparent. Long constraint delay (LCD) data services have been designed within the UMTS framework to provide QoS's which are equivalent to service frame erasure rates (SFER's) of around 10^{-3} .
20 Thus, as there is a lower limit restriction on Δ for channel tracking purposes, the step-up size $K\Delta$ becomes very large and much excess power must be transmitted in order to meet QoS. This would significantly reduce network capacity, especially when considering the fact
25 that each high data rate LCD user consumes much more of the power resource within a cell than each low data rate (e.g., speech) user.

The problem here can be summarised in a more generic
30 form. The outer loop exists to track the channel

variations in speed and dispersion which may be occurring over a time (e.g., 0.5 - 5 seconds). As an example, a vehicular user may transition from 120kmph to close to 0kmph in less than 5 seconds, where the
5 change in Eb/No at QoS will perhaps be of the order of 2dB's. The 'sawtooth' outer-loop algorithm is driven solely by CRC fail information which, by definition, only occurs very infrequently (e.g., $SFER = 10^{-3}$). Considering a typical UMTS LCD circuit-switched data
10 service with service frame duration of 80ms, this gives rise to one service frame erasure approximately every 1.5 minutes for $SFER \approx 10^{-3}$! Therefore, for any reasonable step-up ($K\Delta$) size, the outer loop will be unable to track the channel variations adequately since
15 the corresponding step-down size (Δ) will have to be set to a very small value. In practical terms the 'sawtooth' algorithm is therefore only applicable to low delay services with service frame erasure rates of 10^{-2} or higher, or for non-real-time (NRT) services
20 employing automatic repeat request (ARQ). For real-time (RT) services with QoS requirements for low error probability another approach is required.

Thus it will be understood that a different approach is
25 required for LCD services that have a potentially long service frame duration and/or very low SFER QoS targets. In these services the influx of quality information into the outer-loop mechanism is inherently of too low a frequency to adequately track any channel
30 variations without resorting to transmitting large amounts of excess power. For any practical value of Δ the excess power transmission required by the

'sawtooth' algorithm will be very high due to the large value that must be assumed by K . Therefore, a more frequent measure of link quality is required to track the channel.

5

This invention is based on the realisation that the channel bit error rate (e.g., after 'RAKE' maximum ratio combining (MRC), but before channel-decoding) corresponding to a particular post channel-decoding QoS
10 is relatively independent of the channel type and speed (it will be understood that RAKE MRC is a technique well known in CDMA systems). That is to say, for any particular QoS, there exists a corresponding channel error rate (ChER) that is by-and-large insensitive to
15 variations in the channel type and speed. Thus, if the ChER at the desired QoS could be found, it would provide a continuous measure to track channel variations in the absence of any other information. However, it may not be desirable to have to set a
20 specific desired ChER for each service and data rate and some automated ChER-target-setting process may be required.

Referring now to FIG. 2, an accurate estimate of the
25 ChER can be obtained from the receiver by comparing a re-encoded version of the decoded information bits with a hard decision on the soft channel bits emanating from the receiver/demodulator. In the scheme of FIG. 2, a receiver/demodulator 20 supplies output to a channel
30 decoder 22 which produces at its output presumed information bits. The channel decoder output is applied to a channel encoder 24 which produces at its output a

re-encoded version of the presumed information bits.
The output of the channel encoder 24 is compared to the
output from the receiver/demodulator 20 and applied to
an integrator 26. The output from the integrator 26 is
5 sampled and reset via a switch 28 at the end of each
desired measurement period to produce at its output a
re-encoded channel error metric (ReEnc_ChER)
commensurate with the received signal portion contained
within the measurement period.

10

It will be appreciated that for certain coding schemes
(e.g., recursive) it may be desirable for the re-
encoded input to the comparator to be derived other
than directly from the decoded bits. A suitable
15 alternative re-encoded metric could be obtained, for
example, by concatenating the codewords corresponding
to the most likely path through a decoder trellis. At
the QoS point, the ReEnc_ChER will be closely
representative of the real channel error rate ChER
20 (since, by definition, the decoded output contains very
few errors). In addition, ChER's of between 10% and 20%
are typical for turbo-coded LCD services at BER's of
 10^{-6} and so the effects of the infrequent errors in the
decoded bits on the re-encoded metric are very small.

25

Referring now also to FIG. 3, based upon the above
principle, an outer loop algorithm has been developed
that has two constituent loops and for convenience will
subsequently be termed the 'dual-loop algorithm' or the
30 'Dual Outer-Loop Algorithm for Power-control' (DOLAP).
As shown in FIG. 3, a received signal is applied to the
information bit recovery arrangement of FIG. 2 to

produce a re-encoded channel error rate metric
(ReEnc_ChER) and a cyclic redundancy check (CRC)
pass/fail signal ($CRC_{p/f}$) which is applied to an 'outer-
loop 1' (36). The ReEnc_ChER signal is applied to an
5 'outer-loop 2' (40) where it is filtered and compared
to a target channel error rate signal ($ChER_{Target}$) from
the 'outer-loop 1' (36) to drive a 'small gain step'
incrementer/decrementer 42. The 'outer-loop 1' (36)
also produces an output which drives a 'big gain step'
10 incrementer/decrementer 38. The outputs from the 'small
gain step' incrementer/decrementer 42 and the 'big gain
step' incrementer/decrementer 38 are combined to
produce a OLT increment/decrement signal ($OLT_{+/-}$) which
is used to derive the inner power control loop
15 threshold signal OLT.

Thus, the 'outer-loop 1' (36) monitors QoS information
in the form of CRC pass/fail events. In response to the
 $CRC_{p/f}$ input, 'outer-loop 1' (36) then sets a target
20 channel error rate ($ChER_{Target}$) for the 'outer-loop 2'
(40), and also outputs relatively large OLT
increment/decrement adjustments (Δ_{big}). In the absence
of further 'outer-loop 1' OLT adjustment events, outer-
loop 2 then attempts to maintain the specified $ChER_{Target}$
25 by comparing a filtered version of ReEnc_ChER to
 $ChER_{Target}$ and adjusting the OLT for the inner PC loop in
smaller steps (Δ_{small}) up or down. Δ_{big} and Δ_{small} may
represent multiplicative adjustments to the OLT in the
linear domain, or additions in the logarithmic domain
30 (in a similar manner as described for the 'sawtooth'
algorithm).

It may be beneficial to take an average of the re-encoded channel error rate metric (ReEnc_ChER) over a longer period in order to reduce its variance before it
5 is used by outer-loop 2. This filtering time duration is irrespective of the service frame duration and data rate.

Considering the outer-loop 1 in more detailed
10 description), the outer-loop 1 performs two functions:

- (i) Monitoring Service Frame Quality-of-Service Indicator (SFQI) information and adjusting the OLT by steps $\pm \Delta_{big}$ accordingly; and
- 15 (ii) Determining $ChER_{Target}$ for outer-loop 2.

Considering firstly the outer-loop 1 function of monitoring SFQI information and adjusting the OLT, the algorithm for this process is as follows. $SFQI_n$
20 indicates whether the n^{th} service frame was found in error. A value of +1 indicates an error whereas a value of -1 indicates a good service frame. On encountering a SFQI indicating a CRC fail, the process checks to see whether a service frame in the last T
25 service frames has also been found in error. If so, the OLT is adjusted by an amount $+\Delta_{big}$. Upon a CRC fail, a counter is reset. In the absence of further errors this counter increments every subsequent service frame until it exceeds the value T. When this happens, T
30 service frames have been received error-free, and the OLT is adjusted by an amount $-\Delta_{big}$. The counter is again reset upon this event.

The algorithm can be expressed algebraically as:-

$$[OLT(n)] = [OLT(n-1)] * \frac{\Delta_{big}}{2} \left(SFQI_n + \frac{T - counter}{\sqrt{(T - counter)^2}} \right) \quad (4)$$

The step size value for Δ_{big} should be large enough to
 5 give an appropriate increment upon an undesired service
 frame erasure event, but must also be small enough so
 as to prevent much excess transmission of power above
 the QoS operating point. A typical value for Δ_{big} may be
 0.25 dB. Although recommendations for step sizes are
 10 given in this example, optimisation of both Δ_{big} and Δ_{small}
 could be performed.

The value of T that results in the desired SFER has
 been found via modelling this outer-loop1 process as a
 15 discrete 3-state Markov process. This modelling
 produces the graph of FIG. 4, which shows $(T * SFER)$ vs.
 $(P_{err(tot)}/SFER)$. From this graph it can be seen that in
 order to achieve the desired $SFER_{Target}$ the counter-
 related parameter T (in equation (4)) must be selected
 20 to be:-

$$T = \frac{1}{SFER_{Target}} \times 0.66 \quad (5)$$

Considering now the second function of outer-loop 1 of
 determining $ChER_{Target}$ for outer-loop 2, it is to be noted
 that the above-discussed algorithm for the first outer-
 25 loop 1 function (monitoring SFQI information and
 adjusting the OLT) has a 'do nothing' state when
 neither a big step up nor a big step down event has
 occurred. In these periods, outer-loop 2 will attempt
 to maintain a constant channel error rate by adjusting

the OLT in small steps up or down in response to a comparison of channel error rate estimate with the channel error rate target. $\text{ChER}_{\text{Target}}$ is set subsequent to a counter reset in the first function (i.e., when a big
5 step up or down has been made). Referring now also to FIG. 5, the following $\text{ChER}_{\text{Target}}$ update process occurs. When a counter reset in the first function occurs (i.e., when a big step up or down has been made), this condition is detected, and a wait period 50 (equal to
10 the delay of the re-encoded channel error rate filter 52) is entered, during which ReEnc_ChER is sampled and averaged (which is occurring anyway for outer-loop 2). After this delay period, the output of the ReEnc_ChER averaging filter 52 is input into a $\text{ChER}_{\text{Target}}$ filter 54
15 that is clocked following every counter reset in the first function. The output of this filter is the actual $\text{ChER}_{\text{Target}}$ to be used by outer-loop 2.

Thus, the combined operation of outer-loop 1 and outer-
20 loop 2 can be summarised as follows. When the first function of outer-loop 1 decides that a relatively large step change in the OLT is required, it is implemented and the new channel error rate is measured. Once filtered using previous such measurements, this is
25 then assumed to be a new acceptable channel error rate target for outer-loop 2 to track. In this way, the outer power control loop is able to adaptively determine the average channel error rate at the desired QoS point for that service (these can be very different
30 for different services). Any variations in the channel can then be tracked quickly by outer-loop 2 without the

need for further CRC event information (which by definition arrives at a very slow rate).

It will be understood that the various filter
5 parameters may need to vary for different service frame durations and different values of $SFER_{Target}$ since these affect the average rate and variance of input information into the $ChER_{Target}$ filter.

10 An initial channel error rate target must be set at the start of a call. The target will be updated following a counter reset in the first function of outer-loop 1. It is desirable to set this initial target to a high error rate (higher than any service ChER at desired QoS) such
15 that in the event that the initial OLT setting is too high outer-loop 2 will drive down the power until the first error is encountered. Following this the process will automatically set its own suitable $ChER_{Target}$. Care must be taken therefore to ensure that the initial
20 value of $ChER_{Target}$ does not enter the $ChER_{Target}$ filter. In the case that the initial OLT target is too low, errors will be encountered and the process will adapt itself accordingly.

25 The function performed by outer-loop 2 is very simple. It accepts two inputs: (i) the filtered version of $ReEnc_ChER$, and (ii) $ChER_{Target}$. Outer-loop 2 simply compares these two values and adjusts the OLT accordingly.

30

It may be desirable that the value of $\Delta_{small\ per\ second}$ is similar to the step-down size $\Delta_{per\ second}$ used in the

'sawtooth' algorithm for speech services in order to ensure that both algorithms have similar channel-tracking capability.

- 5 Simulation tests have shown that power control
utilising the above-described dual loop (DOLAP) scheme
allows desired QoS to be maintained for low-FER/high-
data-rate services. The simulation tests also showed
that power control utilising the above-described dual
10 loop (DOLAP) scheme coped well with changes in channel
conditions, the control loops adapting to the changes
without the need for CRC failure.

It will be appreciated that although the invention has
15 been described above in the context of a CDMA system,
the system does not need to be exclusively CDMA. For
example, the invention could be used in a hybrid
CDMA/TDMA system.

Claims

1. An apparatus for power control in a system for radio communication between a first station and a second station, the apparatus comprising:
5 power indication means at the first station for communicating to the second station an indication of the received power of signals at the first station; and
10 power control means at the second station for receiving the indication of received power from the first station and for accordingly modifying its transmission power;
wherein the power control means comprises inner
15 control loop means for producing a power control metric; outer control loop means for producing an outer loop threshold signal (OLT) dependent on received quality of service (QoS),
characterised in that the outer control loop means
20 comprises means for producing a channel error rate signal (ChER) whereby to track channel variations.
2. An apparatus as claimed in claim 1 wherein the means for producing a channel error rate (ChER)
25 signal comprises:
means for producing an information signal containing coded information bits;
means for decoding received information bits from the information signal,
30 means for re-encoding the decoded information bits; and means for comparing the re-encoded version of the decoded information bits with the

information signal to produce the channel error rate signal.

3. An apparatus as claimed in claim 1 or 2 wherein
5 the outer control loop means comprises:
first outer loop means for monitoring cyclic
redundancy check pass/fail events and in response
thereto setting a target channel error rate; and
second outer loop means for receiving the channel
10 error rate signal and for comparing it with the
target channel error rate signal from the first
outer loop means.
4. An apparatus as claimed in claim 3 wherein the
15 first outer loop comprises means for automatically
updating the target channel error rate.
5. An apparatus as claimed in any preceding claim
wherein the system is a code division multiple
20 access (CDMA) system.
6. A method of controlling power in a system for
radio communication between a first station and a
second station, the method comprising:
25 producing at the first station and communicating
to the second station an indication of the
received power of signals at the first station;
and
receiving at the second station the indication of
30 received power from the first station and
accordingly modifying the second station's
transmission power;

wherein the step of producing at the first station
comprises producing in an inner control loop a
power control metric; producing in an outer
control loop an outer loop threshold signal (OLT)
5 dependent on received quality of service (QoS),
characterised in that the step of producing the
loop threshold signal (OLT) comprises producing a
channel error rate signal (ChER) whereby to track
channel variations.



Application No: GB 9914530.2
Claims searched: 1 to 6

Examiner: M J Billing
Date of search: 18 November 1999

Patents Act 1977 Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): H4L LDH.

Int Cl (Ed.6): H04B 7/005; H04Q 7/32.

Other: ONLINE - EPODOC, WPI.

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	EP0853393A1 (NTT) - Figs.2-4	1,6 at least
X	EP0847146A2 (NEC) - Figs.1,4; column 11 line 46 to column 12 line 40, column 13 line 45 to column 15 line 2	1,6 at least
X	EP0715423A1 (A T & T) - Figs.2,3	1,6 at least
X	EP0709973A1 (NTT) - Fig.7; column 8 line 39 to column 9 line 9	1,6 at least
X	WO98/58461A1 (ERICSSON) - page 3 lines 8-25, page 8 line 24 to page 9 line 15	1,6 at least
X	WO97/34434A1 (MOTOROLA) - Figs.3,4	1,6 at least
X	US5333175 (BELL) - Figs.3-5; Abstract	1,6 at least
X	US4777653 (T R T) - column 4 line 45 to column 8 line 61	1,6 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.